Monitoring of Arctic Conditions from a Virtual Constellation of Synthetic Aperture Radar Satellites

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LONG-TERM GOALS

Utilize a constellation of satellite radars to monitor the melting and freezing cycles of the Arctic Ocean north of 65^{o}. Satellite data collections will support in-situ buoy clusters and ice camps as well as sea-going experiments with gliders and drifting buoys. From difference maps of timeseries of images deduce changes in ice extent, ice-type, and lead expansion/contraction with temporal resolutions from hours to days. Ultimately provide a routine Arctic coverage and generate products for operational purposes, and as validation, boundary conditions, and initialization to numerical ice-ocean forecast models.

OBJECTIVES

a) Provide daily Arctic situational awareness from the CSTARS SAR satellite constellation.

b) Develop a Neural Network algorithm for ice-type classification from SAR attributes (e.g., backscatter, incidence angle, polarization) as well as optical data to differentiate between new-, first-, and multi-year ice, and open water.

c) Estimate the percentage of melting ponds from high-resolution SAR images.

d) Combine optical and radar images to track ice floe movement.

e) Generate difference images with temporal resolutions of hours to days between Arctic coverage and ice-type mosaics to illustrate changes in ice extent, ice edge, leads, and ice-types.

f) From amplitude and coherent change detection (ACD and CCD) images estimate global spatial rate of melting during the summer months and freezing during the winter months.

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g) Monitoring of icebergs and the their speed of motion.

APPROACH

2014 MIZ Main Experiment: Starting in April to mid-October 2014, CSTARS provided satellite data collections for four different efforts during the Marginal Ice Zone (MIZ):

(1) monitoring large-scale MIZ evolution in the Central Beaufort Gyre, MIZ buoy clusters, BGEP Moorings, and SIZRS area
(2) tracking medium- and small-scale ice conditions along the drifts of the MIZ buoy clusters
(3) monitoring small-scale ice conditions at BGEP Moorings A and D
(4) detailed monitoring of conditions along the ice-edge

The following resources are requested, as the minimum level needed, to support these tasks:

Target	Mode	Platform/Instrument	Images
Large Scale MIZ Evolution	Background Apr-May: 1 image / 7 days Jun-Sep: 1 image / 3 days	**Radarsat II, ScanSAR Wide** *500 km x 500 km scene, ~100 m resolution, dual-pol (HH, HV) preferred*	48 (CSTARS)
Large Scale MIZ Evolution	Event Response 4 image/day over 2, 3-day-long periods	**Radarsat II, ScanSAR Wide** *500 km x 500 km scene, ~100 m resolution, dual-pol (HH, HV) preferred*	24 (CSTARS)
Buoy Clusters	Background Apr-May: 1 image / 7 days (x4) June-July: 1 image / 3 days (x4) Aug-Sep: 1 image / 3 days (x5)	**TerraSAR-X, Single-Pol StripMap** *30 km x 50 km scene, 3 m resolution, HH*	240 (CSTARS)
Buoy Clusters	Event Response 4 image/day over 2, 3-day-long periods	**TerraSAR-X, Single-Pol StripMap** *30 km x 50 km scene, 3 m resolution, HH*	24 (CSTARS)

Large Scale Evolution of the MIZ
The large-scale, MIZ-evolution images will include the locations of the five buoy clusters, the BGEP Moorings A and D (presently outfitted with an AWAC instruments) and a large portion of the SIZRS line. These images will capture the overall evolution of the marginal and seasonal ice zones.

Large-scale images in the Central Beaufort Gyre (500 km x 500 km, and positioned in times to capture the ice edge and the buoy clusters) will provide overviews of ice edge position, marginal ice zone width, low resolution FSD evolution, and sea ice deformation. They will allow us to identify where break-up begins and how the MIZ evolves. They will provide data suitable for design and validation for models being developed as part of MIZ-DRI (e.g. MIZMAS) by providing statistics that can be compared with models. High-resolution images (< 100m), while important for process studies, will not give this information. MODIS/VIIRS images are frequently obstructed by clouds and do not provide a reliable alternative for this information. Current passive microwave instruments (AMSR-II) are too low resolution.

Buoy Cluster Tracking
Some of the key goals of the buoy arrays are to examine the ice and ocean dynamics leading up to the transition into the MIZ, break-up of floes (and, thus, floe-size distribution [FSD]), and the dynamic-thermodynamic coupling of the ice decay. From remote sensing, we want to observe three things:

1. The change in the ice FSD before, during and after dynamic events.
2. The connection between ice deformation and the decay of the ice cover, which is linked through open water production (and hence solar energy absorption). For this, it is important to observe open water fraction and its connection with high-frequency dynamics. This requires sub-daily repeat imagery.
3. High resolution images (1 to 2 m resolution) are required to monitor the evolution of cracks and leads as they develop and refreeze in the winter and, then, melt out during the summer. FSD estimates from high-resolution images will also be used as a check on FSD estimated from the medium-scale images.

For this, several time periods were examined: (1) early in the summer season, when the ice is reasonably solid, (2) beginning of break-up and melt, and (3) evolution into an MIZ and melt, with small floe sizes.

Background Monitoring
Radarsat-2 Wide ScanSAR images (500 km x 500 km, 100 m resolution) were used to monitor ice conditions across the Central Beaufort Gyre region. These images captured the large-scale evolution of the ice cover and also captured for the most part all of the deployed MIZ assets through the summer season. TerraSAR-X Single-Polarization StripMap images (30 km x 50 km, 3 m resolution) were used to monitor ice conditions local to the five buoy clusters. The 4 buoys of the main array were initially separated by about 100 km (Figure 1). These background images were collected initially every three days and then accelerated to daily observations especially during the height of the melt season (late July-Sep) and collected every seven days prior to this.

WORK COMPLETED

Daily planning, tasking, collecting and processing of TerraSAR-X, Cosmo-SkyMed and RadarSat-2 imagery for tracking 5 buoy clusters required tasking the satellites as little as 12 hours before imaging. Most of the acquired images were successful to include the buoy clusters. In addition we also collected TerraSAR-X images over the ICEX buoy which located north of 85^{o} near the pole. The combined image dataset will allow for a detailed analysis of the ice conditions such as floe size distribution, open water leads and ice types in the vicinity of all the buoy clusters and how they evolved during the melting period in the summer. Figure 1 shows the distribution and locations of the satellite collections during the 2014 main experimental period starting in April to mid-October. A break-down of the different images collected over the buoy clusters during the 2014 main experimental phase of the MIZ program are listed in Table 1. More than 1,140 satellite SAR images from different sensors and in different modes were acquired.

Using image data from the 2013 Pilot Experiment we began to apply ENVI's neural network which is a *supervised* classification technique, used to cluster pixels in a dataset into classes corresponding to *user-defined* training classes. This technique uses standard back-propagation for supervised learning – calculates the gradient of a loss function with respects to all the weights in the network. Goal is to minimize this cost function. Selected regions of interest (ROIs) must be fed into the network, in order to train the data you wish to classify. These add the "weights" needed in calculations. The ROIs will be used to separate image into separate classes, but must be pre-determined. Training parameters and contributions must be further tweaked according to desired classification goal. Figure 2 shows an

example of the Neural Network classification technique applied to an 18 km^2 TerraSAR-X subset image from 1 July 2013 @ 02:53:40 UTC over IMB Buoy 2012L.

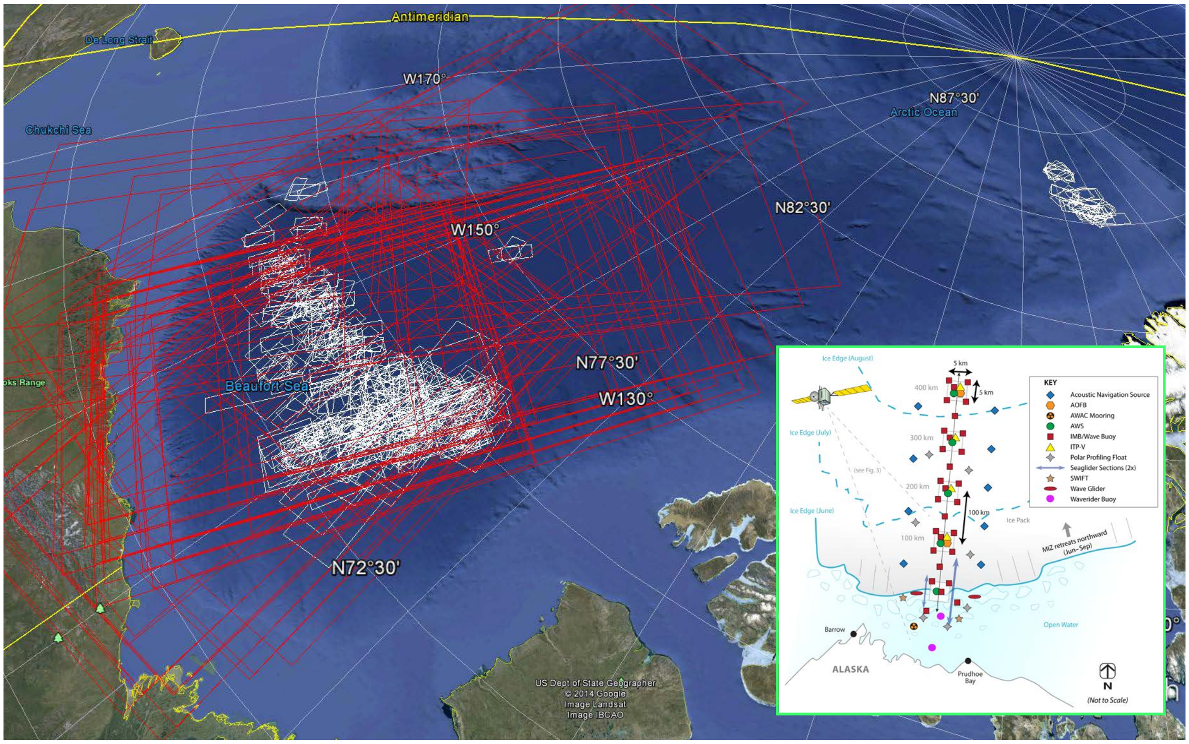

Figure 1: The 2014 satellite collection plan. The footprints in red are RadarSat-2 images for synoptic observations. The footprints in white are TerraSAR-X images for tracking the buoy clusters. The inset shows the schematic of the buoy cluster deployment.

Table 1: List of projects, satellite sensor and imaging modes, the spatial resolution and the number of collects for the 2014 main experimental phase. (The additional collects in parentheses could also be acquired).

Project	Sensor & Mode	Resolution	# of Collects
ICEX Buoy	TerraSAR-X -- StripMap	3 m	33
Buoy Cluster 1	TerraSAR-X -- StripMap TerraSAR-X – ScanSAR CosmoSkyMed -- Himage	3 m 16 m 5m	78 14 1
Buoy Cluster 2	TerraSAR-X -- StripMap TerraSAR-X -- ScanSAR	3 m 16 m	110 22
Buoy Cluster 3	TerraSAR-X -- StripMap TerraSAR-X – ScanSAR CosmoSkyMed -- Himage	3 m 16 m 5 m	88 17 1
Buoy Cluster 4	TerraSAR-X -- StripMap TerraSAR-X – ScanSAR CosmoSkyMed -- Himage	3 m 16 m 5 m	68 8 1
Buoy Cluster 5	TerraSAR-X -- StripMap	3 m	43
Gliders, Prudhoe Bay	TerraSAR-X -- StripMap TerraSAR-X – ScanSAR CosmoSkyMed -- WideRegion	3 m 16 m 50 m	70 7 5
Synoptic View	RadarSat-2 -- ScanSAR	100 m	109
TOTAL COLLECTION			675 (464)

The Neural Network's main parameters are choosing the ROIs which are used to train the network. These training pixels that represent values of water, multi-year ice and first year ice will be used to train the algorithm to "recognize" pixels with similar weighted values, and thus will be classified in the groups that the weights fall into. Other parameters like the training rate, training momentum have to be tweaked [on-going research]. Thus the outputs are: a) Classified Result and b) Rule Result. For the example in Figure 2, three classification regions of interest were selected to train the Neural Network: 1) Water; 2) First Year Ice; and 3) Multi Year Ice. The initial values were taken from expected dB values (Sandven et al., 1999).

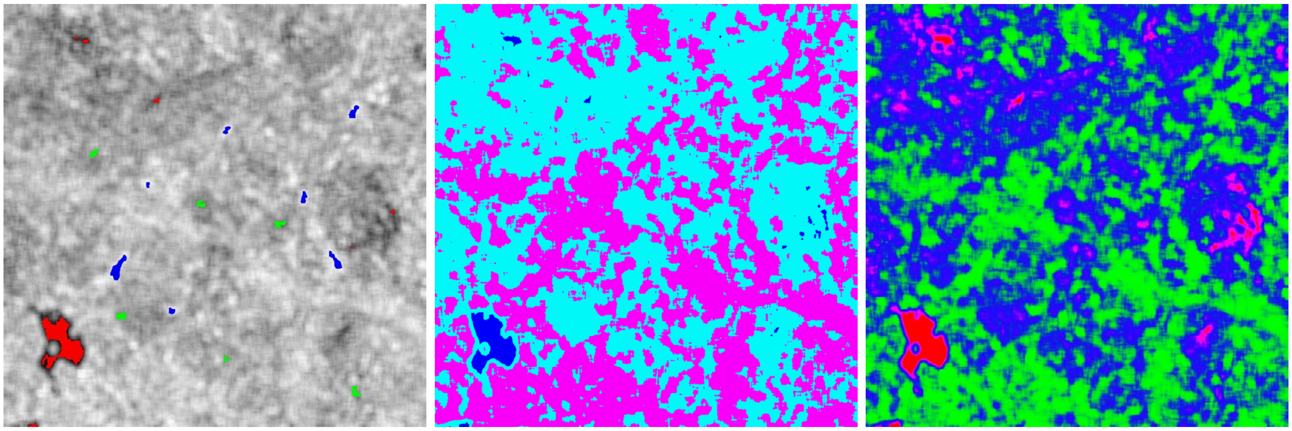

Figure 2: Left: De-speckled TerraSAR-X image from 1 July 2013 @ 02:53:40 UTC showing the three training ROIs: Water (red); First Year Ice (blue) and Multi Year Ice (green). Center: TerraSAR-X Neural Network classified image showing the class distribution. Right: The TerraSAR-X rule result image which can create intermediate classification before final assignment classes.

This application of the Neural Network technique to classify ice in the TerraSAR-X subset image yielded the following class distribution results:

Water = 1% = 0.18 km^2
First Year Ice = 45% = 8.1 km^2
Multi Year Ice = 54% = 9.72 km^2

RESULTS

We have successfully implemented and executed a significant satellite SAR collection program during the 2014 MIZ Main Experiment Program supporting various buoy cluster tracking projects in different regions within the Beaufort Sea and Arctic region.

IMPACT/APPLICATIONS

The potential impact of these satellite collections and analysis studies by this project and other MIZ investigators will lead to an improved algorithm of ice edge detection and ice type classification as well as floe size distribution. Also the project will demonstrate that obtaining a daily satellite imagery of the MIZ covering the entire Arctic region is feasible with the constellation SAR satellites available to CSTARS. Furthermore, the data will lead to considerable improvement of the Navy's ice prediction model.

RELATED PROJECTS

Radar Remote Sensing of Ice and Sea State and Air-Sea Interaction in the Marginal Ice Zone
N00014-13-1-0288

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Sandven, S., O.M. Johannessen, M.W. Miles, L.H. Pettersson, and K. Kloster, 1999: Barents Sea seasonal ice zone features and processes from ERS-1 synthetic aperture radar: Seasonal Ice Zone Experiment 1992. *J. Geophys. Res.,* **104**(C7), 15,843-15,857. doi: 10.1029/1998JC900050